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Active Reception Antennas: Observations, Calculations and Experiments

The idea of combining antennas with active components has existed for about 60 years, but it was only 30 years ago that it began to be introduced into technical reality. The capacitive broad-band antenna did not become possible until depletion layer field effect transistors were available, which was at the beginning of the seventies. Since then, extensive antenna equipment has no longer been required for the reception of the extremely long wave, long wave, medium wave and short wave ranges.

There is a second important application for active antennas in measuring techniques. They can be dimensioned in such a way that they have a constant conversion factor between the output voltage and the field strength over a wide frequency range. They are thus ideal for use in field strength measurements.

It was this second application which stimulated me to assemble my first active antenna in 1974. There were noise field strength measurements to be taken in relation to the preparations for Central Office for Telecommunications Technology inspection tests, which at that time were still carried out in the open air, using adjustable-length dipoles, which were mounted on rotatable masts with adjustable heights. The field strength conversion factor was read off from tables or nomographs, which gave ample opportunity for false readings or errors.

The circuit developed at that time is reproduced almost unchanged here. Even at that time, it was distinguished by the fact that the input capacity was infinitesimally small and the source resistance, which the receiver sees, was pretty accurately 50Ω. Questions of low noise levels and low distortion were in the background in those days. But they have to be tackled if we are to try and obtain the best possible reception, as is expected from an active antenna today.

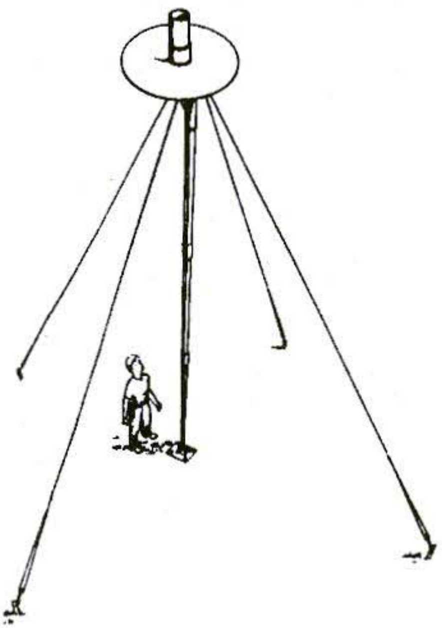

Fig.1: Standard Commercially Available Active Antenna from 1974 on a High Mast ***Picture from Brochure (11)***

1. INTRODUCTION

If we now return to the same topic 20 years later, it's a good idea to see how far technical progress has come over this period of time:

The theoretical principles behind active antennas had already been developed between 1960 and 1975, and were published in such well-thought of journals as the NTZ and the IEEE Transactions. I would prefer not to go through the mathematical work again, as good summaries are available - e.g. from Meinke & Gundlach [7] and Rothammel & Krischke [8]. Jirmann [5] has already used Diagram 1 from the first book in his article. I shall follow this example and use other diagrams from Hütte [1] and from Meinke & Gundlach [7].

As the capacitive broad-band active antenna is set up vertically for omnidirectional reception, the question arises of whether this is actually correct - i.e. in other words, whether the polarisation of the incident radiation is really predominantly vertical. Mature and experienced radio amateurs - among whom I do not count myself - can undoubtedly bring great competence to this question. I've read it up in the aforementioned books, and also in the older Meinke & Gundlach publication [6], in Vastenhoud [9], and in Weeks et al. [10]. The practicing radio amateur may still find it worthwhile to hear about what I found there. Weeks et al. [10] contains an outline of the energy transfer at an interface between air, with $E_r = 1$, and water, with $E_r = 81$, explained in a way which is easy to remember, which is why this article is mentioned here.

One of the first commercially available active antennas was the AA300 from Standard Radio & Telefon AB [11]. At that time, its introduction onto the market gave me the incentive to carry out my own experiments. Fig.1 is taken from the prospectus. It has rather a deterrent effect in the perspective selected by the artist, due to the high mast. And the question should therefore be investigated of whether such a mast is actually necessary, or at any rate at least advantageous. The antenna has a baseplate with a considerable diameter,

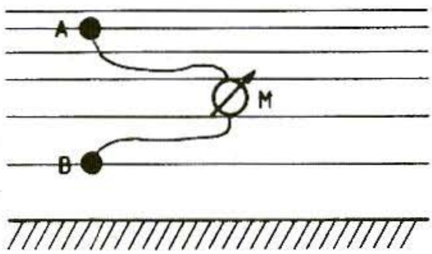

Fig.2: Metallic Conductors A and B receive the Potential from the corresponding Potential Lines. The Difference is displayed high-ohmically by the Measuring Apparatus M

which I simply copied at the time. Today, the question arises of whether it is necessary, harmful, or simply superfluous.

The proposal in [2] to use a CB radio groundplane as a short-wave reception antenna comes from me. In [3], I explained a probe which can be used to measure field strengths. It remains to be tested how far the results obtained then have to be reviewed.

The capacitive broad-band active antenna can be created only because the ambient noise intensity levels rise considerably at low frequencies. In the Hütte [1], I found a diagram which determines the noise field strength directly, and thus supplies the calculation data required for an antenna which converts the field strength into a voltage.

Internal noise from the amplifier used naturally plays an important role. The selection of the correct transistor for the input stage and the influence of the passive antenna fraction should be represented. For this, we also need a book in which the relationships are shown in a comprehensible manner, which is why the Connor [49] can be found in the reference literature.

Finally, we should not be content with the theory. The antenna should be given a practical test. The groundplane from [2] can act as a comparison, using the short-wave receiver described there.

2. THE PASSIVE ANTENNA FRACTION

The capacitive broad-band active antenna is a receiver which registers potential difference between two points

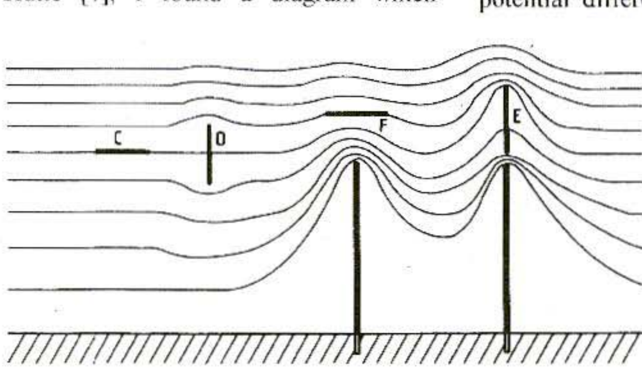

Fig.3: Field Distortion due to Metallic Conductors, which are insulated or connected to Earth

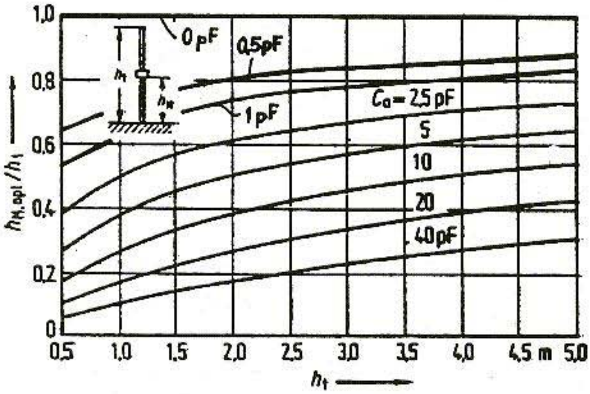

Fig.4: Optimum Height, hM, optimum for the De-Coupling of the Reception Voltage according to Meinke & Gundlach (7) with newly plotted Curves for 0; 0.5 and 1 pF

in an electrical field. Fig.2 shows equipotential lines parallel to the earth's surface. The intervals between them diminish as the height increases. Two metallic conductors, A and B, which here are spherical in form, receive the potential from the corresponding lines. A high-ohmic measuring apparatus, M, shows the potential difference as a voltage. Direct calibration in field strength units (V/m) is possible if the interval between the conductors remains constant and is always vertical to the potential lines.

The potential difference source impedance can be measured and calculated as the capacity between the two conductors. The loaded impedance of the measuring apparatus must be high in relation to this, if the voltage is to be measured correctly and independently of the frequency. An input capacity in the measuring apparatus means the voltage displayed can be lower, while still remaining independent of the frequency. The highest voltage is undoubtedly obtained with a ball in contact with the ground.

The conductors should on no account be spherical in shape, as these are not easy to manufacture using machine tools. Fig.3 gives examples of other shapes. A horizontal conductor, C, does not interfere with the field pattern. It can take the form of a rod or a plate. A vertical rod, D, by contrast, distorts the field, because in its immediate environment only the mean potential can prevail, which it then also acquires itself. A mast connected to the ground means considerable field distortion. A feed cable to the upper section E or F, or an earth wire has precisely the same effect. The vertical rod, E, or the horizontal conductor, F, thus obtain a lower potential than would be present for their height with an undisturbed field. The field strength is reduced on the ground in the vicinity of the masts. This shading also takes place in the vicinity of houses and trees, and in even more pronounced form within houses and under bridges.

The feed to the measuring apparatus in Fig.2 goes through several potential lines, and also creates field distortion (not shown here). The effect becomes more and more disadvantageous as the capacity of this feed towards the environment increases. It can thus be of use

to hold the actual receivers with support insulators and to make the feed extremely thin. If the influence of the feed is then discounted, the conversion factor can rapidly be estimated. If the interval between conductors A and B is, for example, a metre, then a field strength of 1 V/m delivers a voltage of 1 Volt. The conversion factor is V/V/m..

The capacities can also be estimated easily, but particularly easily if balls are involved. Older readers will remember that previously the unit of capacity was defined by means of a ball bearing with a radius of 1cm. in space. This ball bearing then had "1cm." capacity, so a ball bearing with a radius of 13cm. had "13cm." capacity. Nature was again very cooperative, and arranged things in such a way that this "1 cm." corresponded fairly precisely with 1pF, so that the 13cm. ball bearing has a capacity of 13pF in space. The vicinity of other conductors (ground, mast, baseplate) can only increase the value determined in this way,which, as we shall see later, is advantageous.

The capacity for other forms can be calculated using the following formulae, taken from Meinke & Grundlach (6):

Circular disc in space (C = capacity in pF, s = disc thickness in cm., D = disc diameter in cm.):

$$C = 0.353 \ D \bullet (1 + 0.637(s/D)) \quad 1$$

Vertical rod at a distance of more than l/4 from the ground (l = length in cm., D = diameter in cm.):

$$C = 0.24 \bullet l \bullet (1/lg) \bullet (l/d) \quad 2$$

Horizontal rod above ground (h = height, l = length, D = diameter)

$$C = 0.24 \bullet l \bullet (1/lg) \bullet (4h/D) \quad 2$$

Some examples may indicate the order of magnitude involved:

For the rod with a diameter of 7mm. and a length of 1 m. which Jirmann [5] uses, the value calculated is 11pF. A thin plate with a diameter of 10cm. gives 3.5pF, and even a thin feed with a diameter of 0.5mm. and a length of 0.5m. already has a value of 4pF.

A layout like Fig.3e can be optimised in accordance with Meinke & Grundlach [7]. This is clarified in Fig.4, which is taken from this book, but which has been amplified by the three curves for the 0, 0.5 and 1pF input capacity of the subsequent amplifier. According to this, with the pre-set mast height, ht, we obtain an optimal height, hM, for the output coupling point, which depends on the amplifier input capacity. If we succeed in making the input capacity zero, then the effective upper part of the antenna can be very short.

The way in which the potential lines are forced back at the tip of the mast indicates that the field strength is greater there than elsewhere. The same is also true above houses and trees. However, all these considerations are valid only as long as the dimensions are small in relation to the wavelength. With an expansion of even 5m. in the upper short-wave range, this no longer applies. The point of having a high mast lies more in increasing the distance from unwanted interference emanating from cars, houses and transmission lines.

And for this reason it can be advantageous, not just to position an active antenna on the roof of a house, but to place it on top of a mast positioned there. Damping a feed can usually be dispensed with until right at the top end of the short-wave range. At a length of 100m., it produces only 2 - 3dB for a measuring frequency of 30MHz with RG-58/U type cable.

3. EXTERNAL NOISE

The thunderstorm activity continuously present on Earth is the origin of the atmospheric noise. It is assumed that 1000 to 2000 thunderstorms are simultaneously active at any given moment, producing about 100 lightning strikes

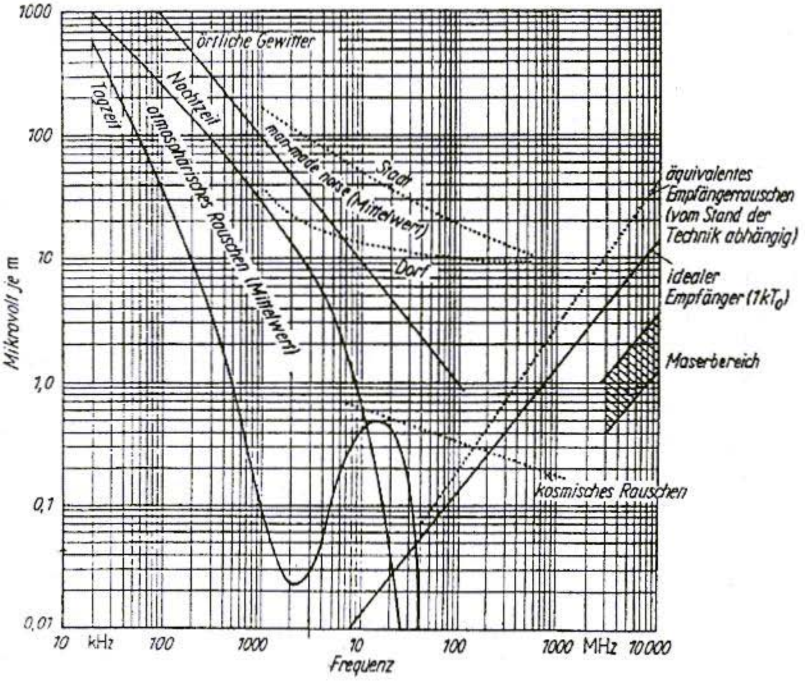

Fig.5:

Noise Field Strength of Various Sources for a Receiver Band Width of 10 kHz according to Hütte (1). A λ/2 Dipole has been used as the Reception Antenna in the Curve for Equivalent Receiver Noise

Tagzeit **= Daytime,** ***Nachtzeit*** **= Night time,** ***Örtliche Gewitter*** **= Local thunderstorm,** ***Atmosphärisches Rauschen*** **= Atmospheric noise,** ***Mittelwert*** **= Mean value,** ***Stadt*** **= City,** ***Dorf*** **= Village,** ***Kosmisches Rauschen*** **= Cosmic noise,** ***Äquivalentes Empfängerrauschen (vom Stand der Technik abhängig)*** **= Equivalent receiver noise (dependent on state of the art),** ***Idealer Empfänger*** **= Ideal receiver,** ***Maserbereich*** **=**

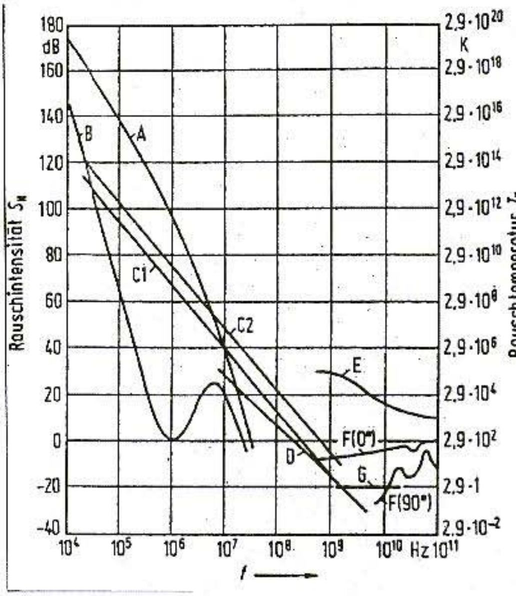

Fig.6: Interference Power Density for Various Sources according to Meinke & Gundlach (7)

A - Atmospheric Noise (Max)
B - Atmospheric Noise (Min)
C1/C2 - Industrial Noise (Country/Town)
D - Galactic Noise
E - Quiet Sun
F - Noise from O2 and H2 at two Angles of Elevation
G - Cosmic Background Radiation 2.7 K

***Rauschintensität* = Noise intensity, *Rauschtemperatur* = Noise temperature**

per second. The propagation of this interference energy is subject to the same laws as those governing electromagnetic waves. The range width is considerably greater by night than by day, the day-night difference being less for long waves. We thus obtain the graph in Fig.5, divided up to show the pattern at night, in the daytime, and during a storm in the area. The diagram is taken from Hütte [1] and the field strengths given are valid for a noise band width of 10kHz, which corresponds to the standardised radio interference measuring apparatus or to an average AM radio.

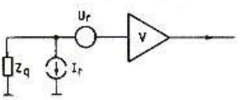

Fig.7: Noise Equivalent Circuit Diagram for an Amplifier. V Noise-Free Amplifier, Zq Source Impedance, Ir Noise Current Source, Ur Noise Voltage Source

A capacitive broad-band active antenna with the conversion factor 1 V/V/m delivers an output voltage which is numerically identical to the field strength. Thus, for example, at 20kHz it emits a noise voltage of app. 1mV at night. In the high-frequency (short-wave) range, the atmospheric, and also the cosmic, noise is usually less than 1µV.

The rising line on the right in Fig.5 represents the noise background for an ideal or actual receiver which is connected to a $\lambda/2$ dipole antenna, converted to the equivalent field strength. We can see that a particularly sensitive receiver is not required in the short-wave range. 20dB worse than 1 kT_0 is still sufficient. The diagram used by Jirmann [5] is shown again here as Fig.6, because it demonstrates an impor-

tant technical advance, as against Fig.5 - a considerable reduction in interference generated by human activity! In the late fifties, it was realised in the industrial countries that interference had to be reduced, so legislation was brought in imposing interference suppression. The introduction of regulations in stages, depending on the state of knowledge at any one time, has led to a situation today where, in spite of a considerable increase in the amount of electrical equipment, the intensity of interference caused by it has decreased. On the other hand, the country I now live in has no legislation on interference suppression to date.

The ordinates for the two diagrams, Fig's.5 and 6, are measured in different units, and are thus not directly comparable. To convert from intensity, which probably corresponds to the power density, into field strength, we must use the effective antenna area and the field strength output voltage formula for the $\lambda/2$ dipole. I shall save myself the trouble, since for the capacative broad-band active antenna the field strength scale is more practical and easier to read.

4. INTERNAL NOISE

The amplifier behind the passive antenna section sees a source, the impedance of which corresponds to a few pF. A low radiation resistance of considerably less than 1Ω has actually no part to play, as the quality remains greater than 100 over the entire range which is of interest.

The internal noise of an amplifier can always be represented in relation to the input - i.e. by a noise voltage source, U_r, and a noise current source, Ir, in Fig.7. The voltage drop generated by I_r at the source impedance, Z_q, combines with U_r to give the total noise voltage, $U_{r\ tot}$. If the noise sources are uncorrelated, the noise voltages are added together geometrically:

$$U_{r\ tot} = \sqrt{(U_r^2 + Z_q^2 \cdot I_r^2)} \qquad 4$$

If they are correlated, the phase angle of Z_q then has to be considered. If it is 0° (ohmic), the voltages are added together arithmetically. With anti-correlation, it is even theoretically possible that the total noise voltage will be smaller than the figure you start with. However, according to Murphy this drop is extremely unrealistic. If Z_q, the phase angle, is + or - 90°, as always with capacitive broad-band active antennas, then equation (4) applies again. For amplifiers which operate in accordance with a tuning circuit, the dependency on the phase angle is the reason why de-tuning in itself can reduce noise.

The lowest inherent noise value for an amplifier is obtained if it is conditional upon the active element in the first stage alone. This can not always be fully guaranteed, for there is a limit to the amplification of the first stage. However, if it is only 1, then the second amplifier stage contributes just as much as in the input stage. We have given away 3dB. The same is true for amplifi-

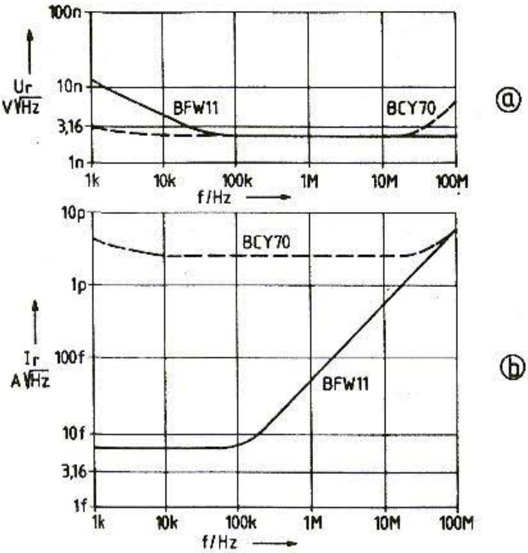

Fig.8: Noise Voltage and Noise Current behave very differently in Bi-Polar and Depletion Field Effect Transistors, as shown here through the Examples of BCY70 (Bi-Polar) and BFW11 (FET)

ers with differential amplifier inputs, because there two transistors are contributing to the noise in the input. An input of this type is necessary with active antennas for horizontal polarisation, but not with those under consideration here. The first transistor can be a field effect or bipolar type. The curves for the Ur and Ir paths, plotted against the frequency, show what has improved. Noise specification is just the area where the manufacturers are very reticent. I found adequate specifications for only a few types. Those in Fig.8 may perhaps be representative. The curves show that, for a low-frequency FET, Ur is somewhat higher than for a bipolar transistor. At high frequencies, the bipolar type performs rather worse. But this may be due to the fact that it is really not intended for high-frequency applications at all. There is no significant difference in the long-wave, medium-wave and short-wave ranges.

I_r behaves in a completely different way. At low frequencies, the noise current from the FET is up to 3 decades less than that for the bipolar type. By contrast, above 50MHz there is no longer any significant difference. Ir rises linearly with the frequency, and the path of Z_q is inverse to this. The product $I_r \bullet Z_q$, which represents the part of the inherent noise voltage generated by the noise current, remains practically the same between 0.1 and 50MHz. With an antenna capacity of 10pF and a 10kHz band width, the value calculated is only 80nV, whereas Ur is already 220nV. Combined together in accordance with equation (4), these values give 235nV. We could thus dimension the passive antenna section to be quite considerably shorter and so lower in capacity. At 3.5pF, the noise fractions attributable to Ir would be about the same as those for Ur. The internal noise would then be about equal to the external noise - i.e. about 0.35μV. These calculations indi-

cate that the capacitive broad-band active antenna would not have been possible without depletion layer FET's.

MOSFET's have a markedly lower noise current than depletion layer FET's, while that of MESFET's is slightly higher. For both, the cut-off frequency of U_r - i.e. the curve bend, at which the 1/f rise begins, is at markedly higher frequencies. Should it prove possible to improve this behaviour in the foreseeable future, they would have the advantage of a higher rate of rise, and thus greater amplification in the first stage. It would make virtually everyone happier if the semi-conductor industry would include more Ur and Ir curves in their data sheets. It would then no longer be necessary to select an appropriate component through trial and error.

5. WAVE PROPAGATION

The frequency range of a capacitive broad-band active antenna can extend, for example, from 10kHz up to 30MHz. Because of this wide range, it is not possible to give a generally valid description of wave propagation. However, it can be stated that the ground can be regarded as a conducting surface at low frequencies and as a dielectric interface at high frequencies. In between, mixed behaviour is present - a dielectric with conductibility, which is characterised by the occurrence of losses. Losses are greater when the polarisation is horizontal than when it is vertical. For particularly wide ranges, the ground wave must therefore be vertically polarised.

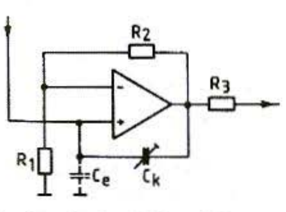

Fig.9: Principle of Compensation for Input Capacitance of an Amplifier

The polarisation initially corresponds to the alignment of the transmission antenna. But after one or more reflections to the ground or the ionosphere, a sizeable orthogonal polarisation fraction is present, so that for long-distance reception it is relatively immaterial what the transmission polarisation was.

Waves with a high wavelength (VLF, very long frequency, or long wave) are carried between the ground and the ionosphere as if in a waveguide and so retain their polarisation. As they are transmitted with vertical polarisation, a vertically active antenna is correct for reception. As losses occur, the field strength vector declines in the propagation direction. But its main fraction is vertical, as before. This applies only to the ground wave, the range of which is in any case reduced when ground losses arise. At shorter wavelengths - i.e. medium and short wave - reflection on the ground involves polarisation. Whilst horizontally polarised waves are always subjected to a 180° phase shift, with vertically polarised waves it depends on the angle of incidence. Shallow waves with a low angle of elevation are reflected through a 180° phase shift.

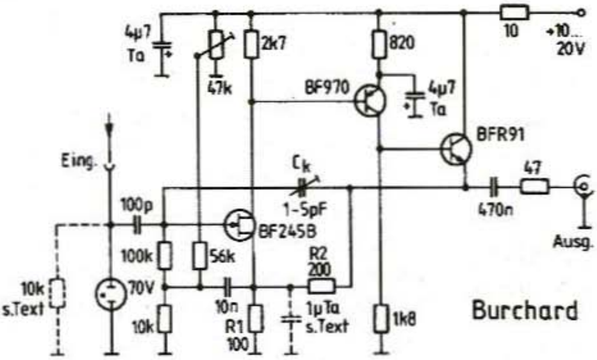

Fig.10: Active Antenna Amplifier Circuit

***Eing.* = Input**
***Ausg.* = Output**

Those with a high angle of elevation come back in the same phase - i.e. they amplify the wave with direct incidence. At one specific angle, the Brewster angle, which depends on the frequency and the ground characteristics, nothing at all is reflected. The reception takes place as if the reception antenna were mounted in free space.

Direct and reflected waves are vectorially combined at the reception antenna. If the reflection phase position is 180°, this results in a reduction in the reception field strength. If not, there is an increase. Thus horizontally polarised waves are always weaker when received than vertically polarised waves. Only at very small angles of elevation (5° to 20°) are they approximately equal.

The longest ranges are obtained above sea water with good conductivity, $Q = 2(\Omega \cdot m)^{-1}$, and a high relative permittivity, $\varepsilon_r = 81$. As 70.8% of the earth's surface consists of sea water, this is very convenient for signaling.

The reflection and attenuation capabilities of the ionosphere are connected to solar radiation, sunspot activity and the earth's magnetic field. There are daily cycles, seasonal cycles and sunspot cycles. Nothing suggests that there are times when vertical polarisation of reception antennas could be unfavourable. Active antennas can also be constructed for horizontal polarisation and can also be directional. But that is outside the scope of this article.

The free space field strength of a 1 MW long-distance station is certainly considerable. It amounts to about 1 V/m at a distance of 10km.. The active antenna must still operate satisfactorily with such field strengths coming from one or more transmitters. This requires a level range free of inter-modulation of more than

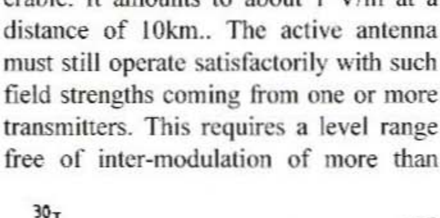

Fig.11: To ensure as little Distortion as possible, the Power Consumption is set to the Optimum Value for Every Operational Voltage

120dB. Even measuring such a value involves the greatest of difficulties.

6. PLANNING

Optimal results can be expected if the capacitive broad-band active antenna is measured for a given receiver. Here I would like to refer to the receiver based on [2], which I actually use for short-wave reception on an everyday basis. It has a noise band width of 7.6kHz, which means there is a difference of only 1.2dB in the noise, as against Fig.5. In relation to the input, the noise level is -107dBm. and the input power which is required for an inter-modulation product of the third order to be generated of the same value is -28dBm. The layout is designed for a broad-band input, 3 - 30MHz.

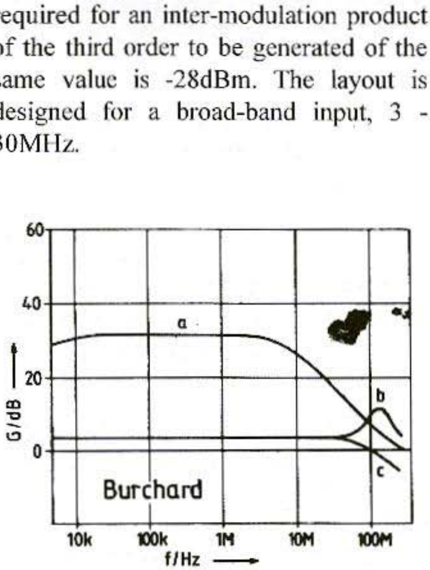

Fig.12: Amplification from Amplifier in Fig.10 without Negative Feedback (a) and with various Coupling Capacitors, with Generator 10pF (c) or 10nF (b)

If the noise field strength is approximately 1μV/m (Fig.5), then a conversion factor of 1 V/V/m should be about right. It can be obtained, for example, through a rod antenna with an effective length of 0.33m. and an amplification of 3. For an effective length of 0.33m., a rod about 0.5m. long is required. The external and internal noise levels at the amplifier output are then approximately equal to the noise background of the downstream receiver.

For short-wave reception of frequencies above 3MHz (high-frequency range), the amplifier must have an input resistance exceeding 10kΩ if the source impedance corresponds to5pF. Including the medium-wave, long-wave and extremely long wave ranges requires 100kΩ, 1MΩ or 3.3MΩ. For the high-frequency (short-wave) and medium-frequency (medium-wave) ranges at least, no bootstrapping of the shunting resistor is required. The output impedance of the amplifier should be as low as possible, so that load variations have no influence. An ohmic series resistance of 50Ω then ensures that the subsequent receiver sees 50Ω. This "reciprocal matching rule" makes sure that the receiver behaves as at the signal generator, and that selective filters in the input are correctly blocked off.

To compensate for the input capacity, a circuit as in Fig.9 is required, in which R1 and R2 determine the amplification and R3 determines the output impedance. The voltage distributor, R_1, R_2, is low-ohmic, so only the non-inverting input of the amplifier needs to have an FET input. Its unavoidable capacity, C_e, is compensated if:

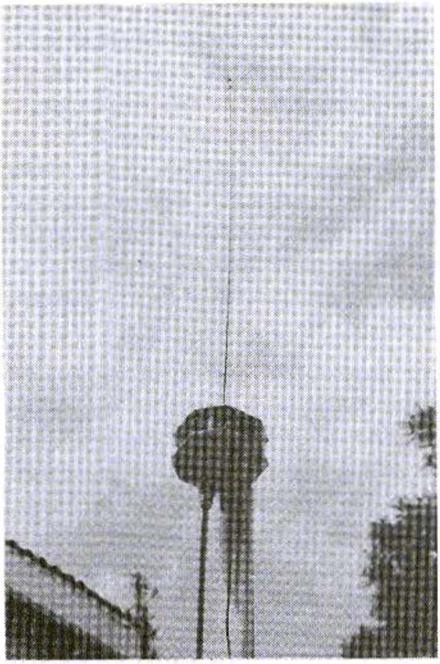

Fig.13: Sandwich Format of Amplifier between two Octagonal Boards made of PCB Material

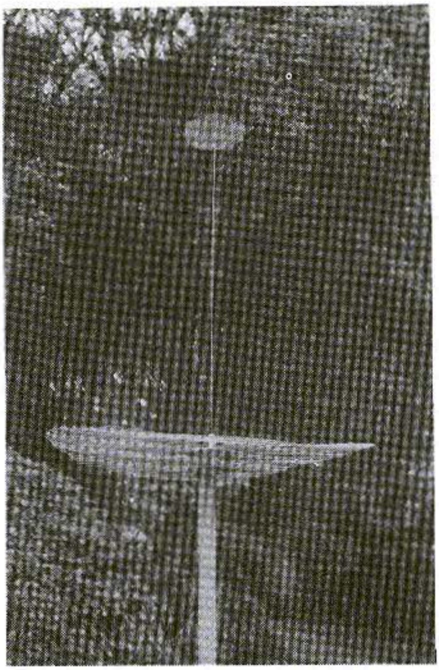

Fig.14: A Roof Capacitor and an Earth Plate can be used for Tests

$$C_k = C_e(R_1/R_2) \qquad 4$$

which is equivalent to neutralisation. Fig.10 shows a suitable amplifier. It has a three-stage layout and can be operated using operating voltages of between 10 and 20 Volts. As the operating voltage increases, the level control capability increases. For every voltage, there is an optimal operating current for minimum distortion, which can be read off from Fig.11. The measurements below were carried out at 15V and 25mA. The current is adjusted using the trimming potentiometer, which compensates the considerable operating point tolerances of field effect transistors at the same time.

The circuit in Fig.10 scarcely differs from the one I used in 1974. Then the first stage was equipped with an NF3819 (i.e. 2N3819 in a metallic TO-18 housing), the second with an AF139, and the third with a BFX59. As these types of equipment can scarcely be obtained today, and the metal housing and its earthing do not seem to be absolutely necessary, I changed over to

the types of component given. A BFW11 could not have been operated here, so a BF245 was substituted for it, which is probably the reason why the noise in relation to the input was greater than Fig.8 predicts.

This amplifier has an open-loop voltage gain of about 30, which decreases linearly above 10MHz and is still about 7 at 30MHz. To measure it, the negative feedback resistance, R_1, should be bridged over at 1µF. Due to the low series resistance, a wrapped capacitor or tantalum capacitor is necessary.

With negative feedback, the amplification is 3, and with a 50Ω load it is 1.5 over the entire frequency range between 10kHz and 30MHz, as shown by Fig.12. The correct setting for C_k can be recognised by the fact that the amplification is the same for low and high coupling capacities at the signal generator.

The resonance type accentuation at 150MHz, with a large coupling capacitor, is connected to its inherent inductance, and can therefore be ignored.

This amplifier may display a tendency to oscillate with an open input and over-compensation of C_e. But oscillation will stop immediately if an antenna with a few picofarads is connected.

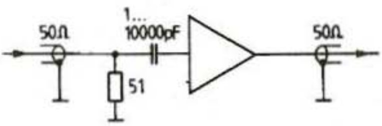

Fig.15: Test Circuit for Amplification, Noise and Inter-Modulation

7. MECHANICAL ASSEMBLY

Two octagonal discs made of single-lined printed circuit board material are arranged one above the other, with interval columns. Their diameter is selected in such a way that a tin can could be put over them to protect them from the rain. The upper one has a banana socket in the middle, into which the antenna conductor is inserted. The lower one has a BNC socket as the high-frequency output and a banana socket as the operating voltage feed.

Using a coax cable for the power supply is initially dispensed with. Fig.13 shows this formation on a mast, from which the discone antenna mounted there was removed for the tests.

The amplifier circuit is mounted between the two detachable discs, which is possible because of the small number of components and the uncritical layout, with the help of a few Minimount supporting points.

Fig.1 suggests that a capacitive broadband active antenna should have a large earth plate. To investigate this, two ¼" flat plugs are mounted on the upper octagonal disc, onto each of which a roughly cut earth plate made of wire netting, with a diameter of 50cm., can be placed with a flat plug at the end, onto which a roof capacitor with a diameter of 10cm. can be placed.

With the two wire netting arrangements, the antenna then looks like Fig.14.

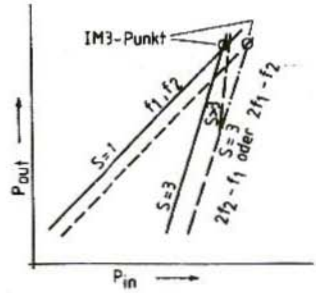

Fig.16: Fundamental Pattern of Signals generating Inter-Modulation with Frequencies f1 and f2, and of Third-Order Inter-Modulation Products with Frequencies 2f2-f1 and 2f1-f2

Punkt **= Point,** ***Oder*** **= Or**

8. MEASUREMENTS AT THE LABORATORY TEST BENCH

If power from a high-frequency generator is transmitted through a resistance with an order of magnitude of 10kΩ into the as yet uncompensated input of the amplifier (C_k = 0pF), then the input capacity of the amplifier can be determined on the basis of the cut-out frequency of the low-pass behaviour. It was measured here as 4.5pF. The banana socket in the printed circuit board material adds 3pF to this, and the glow lamp contributes 0.3pF. The input capacity to be compensated is thus 7.8pF. C_k must theoretically be set at 3.9pF. But in practice it is much simpler to set C_k in such a way that the same amplification is present with a small coupling capacitor - i.e. about 10pF - at the signal generator as with a very big coupling capacitor - i.e. about 10nF. That was already a pre-condition for Fig.12.

The capacity of the antenna conductor can be measured with a universal measuring bridge. The result was 4pF, which correlated very well with equation (2). Adding the roof capacitor on increases it by 3pF, which also correlates very well with equation (1). The influence of the earth plate on the antenna conductor capacity is extremely small. 0.5 and 0.2pF increases were measured for the rod and the roof capacitor respectively.

The open-loop voltage gain and composite gain are measured in a circuit as per Fig.15. The results have already been indicated above (Fig.12). In this circuit, which is also suitable for measuring noise and inter-modulation, the input power supplied from the signal generator is fed to the 51Ω resistance. The capacitive broad-band active antenna picks up virtually no power, for which reason the signal generator must be artificially closed off. Although the typical power amplification measured with the circuit in Fig.15 is 3.5dB, it is actually very high!

The output of the circuit in Fig.10 can supply a maximum current of $15mA_{eff}$. This is sufficient for a yield of 10mW (+10dBm) at 50Ω, or a peak voltage of ±1V. Although an oscillogramme indicates hardly any distortion for this output power, this does not supply proof that the 120dB inter-modulation intervals desired have now been obtained. Unfortunately, the true picture looks very much darker.

A tried and trusted measurement for the absence of distortion is the interval between the third-order inter-moduilation products and those generating two signals of the same size. It can be demonstrated that the levels of these inter-modulation products rise three times as steeply as those for the generating signals. This is true as long as the characteristics can be described by a Taylor expansion as far as the third grade and all higher grades can be dispensed with. Fig.16 shows this relationship. The steepness gradient (S = 1 or S = 3) is thus initially valid for low-signal operation. But the curves are extended until they cross at the intersection point, and we then read off the input or output power at the interception point as the IM3 point at the input or the IM3 point at the output. The higher this point is, the better the amplifier! If the low-level signal operation is ignored during measurement, then the curve for the inter-modulation product is steeper, because higher powers of the Taylor expansion are taken into account. This can be seen from the path of the dotted line in Fig.16, which initially runs parallel to the S = 3 curve, but then bends steeply upwards if, for example, limitation occurs. The IM3 point to be given here is located in the extension of the bottom part of the curve along the dot-dash line. The dotted inter-modulation product curve is derived from the solid line through negative feedback. The linearity is increased, so the IM products are decreased. The amplification is reduced, but the inter-modulation interval increases.

The measurement guidelines can be derived directly from this. The generating signals are to be reduced until the

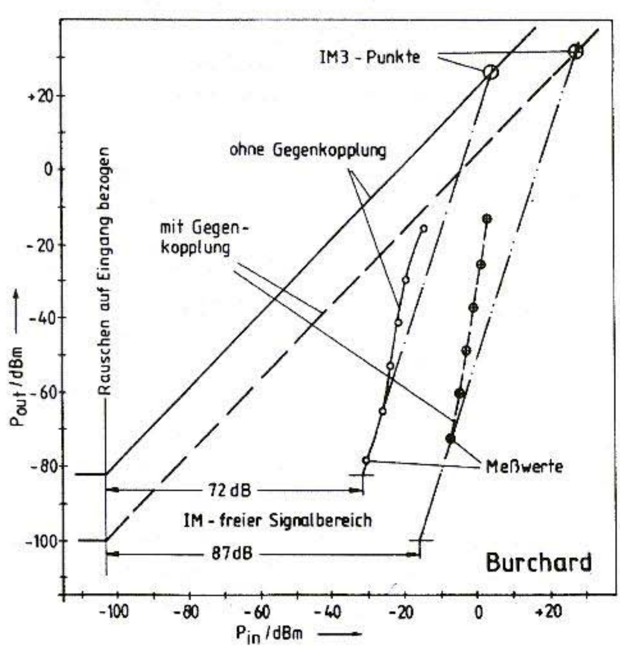

Fig.17: Amplifier Readings according to Fig.10 at 15V Supply and Measurement Freq's f1 = 19.8MHz and f2 = 20.2MHz

Rauschen auf Eingang bezogen **= Noise in relation to input, *Punkte* = Points, *Ohne Gegenkopplung* = Without negative feedback, *Mit* = With, *Meßwerte* = Readings, *IM-freier Signalbereich* = "IM-free signal range**

inter-modulation products with a gradient of 3 decrease. If you have discovered one or more points on the S = 3 curve in this way, then carry on the extension with this gradient up to the interception point.

The signal generators for IM3 measurement must emit relatively high signal levels, and must therefore operate with little attenuation in the calibrated attenuator. If they are inter-connected through a simple T-piece, then power also goes from the one generator into the output of the other. A rectifier, for example, is connected up there to measure the input voltage of the calibrated attenuator. Due to its non-linearity, it also creates inter-modulation products, which can call the entire measurement process into question. A power combiner can provide a remedy (example: PSC2-2 from Mini-Circuits) by inter-connecting the generators, together with additional buffer amplifiers between the generators and the combiner, as well as an external calibrated attenuator after the hook-up. This last makes it possible to operate the generators with constant coupling, and thus with the inter-modulations conditional upon it. If they are too high, then Fig.16 gives an inter-modulation curve which runs parallel to the signal curve.

The IM products are measured through a selective receiver. That can be, for example, the short-wave receiver described in (2), or even a spectrum analyser. In the second case, we have the advantage that we can see all the products simultaneously, whereas the short-wave receiver must be tuned to them one after another. One would initially think that the selective receiver itself must have better IM characteristics than the object of measurement. However, under favourable circumstances it is possible to overcome these obstacles. The question, as can be seen from Fig.17, is whether a measurement point on the S = 3 curve can still be reached using the level range of the receiver, which can still be measured with certainty and is free from inter-modulation. If we make the conservative assumption that the lowest reading with negative feedback (open circuit) is already on the S = 3 curve, in this case there is a signal range of at least 87dB free from IM. Without negative feedback, it is only 72dB. Thus the only requirement for the inherent inter-modulation of the receiver is that it should still play no part if the difference in levels is 70dB. This is the case for the receiver described in (2), and also for many spectrum analysers. We can now read off the IM3 points without negative feedback from Fig.17 at +4dBm (input) and 26dBm (output). With negative feedback, they improve to at least +27dBm (input) and +31dBm (output).

To measure still more extensive IM-free signal ranges with an inadequate receiver, a notch filter is required between the object of measurement and the receiver. It considerably lowers the generating signal, but allows the IM products to pass. As it can be implemented only passively, the distance between the two measurement frequencies must then be considerably increased.

The receiver noise amounts to -107dBm in relation to its input, so its fraction is -110dBm (0.7μV) at the input of the

active antenna. The active antenna noise and the receiver noise are geometrically combined in accordance with an equation similar to equation (4). Here we are measuring the voltage noise with a large coupling capacitor, with the receiver noise at -109dBm (0.8µV), plus the current noise fraction included at 5pF coupler C -104dBm (1.3µV) and at 10pF coupler C -106dBm (1.1µV). From this we can calculate $U_r = 0.4\mu V$ (-115dBm) in addition to $Z_q \bullet I_r(5pF) = 1\mu V$ (-107dBm) or else $Z_q \bullet I_r(10\ pF) = 0.5\mu V$(-113dBm). The IM-free range for the entire system of active antenna and receiver is naturally smaller than that for the individual components, namely 73dB with an antenna capacity of 5pF or 75dB with 10pF. The loss is small, because the two components have been tuned to one another.

The amplifier current noise turned out to be much greater than one would have expected from Fig.8. This may come from using a different type of FET. An experiment in which the component was replaced by a BF244 produced no significant alteration.

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Active Reception Antennas - Observations, Calculations and Experiments
Part-2 (Conclusion)

9. MEASUREMENTS UNDER OPERATING CONDITIONS

On the workbench, it could already be established that numerous stations could be heard on all short-wave bands. For comparison with the groundplane antenna recommended in [2], however, the capacitive broad-band active antenna had to be on the roof. There was already a mast at an appropriate place on the roof of the house (Fig.18), at which a discone antenna had been mounted up till then. The height of the two antenna heads was then the same - 7m above the ground. The expected improvement in reception did not materialise. The short-wave range was crammed with inter-modulation products.

When an oscilloscope was connected using a 50Ω through coupler, this soon made it clear that medium-wave trans-

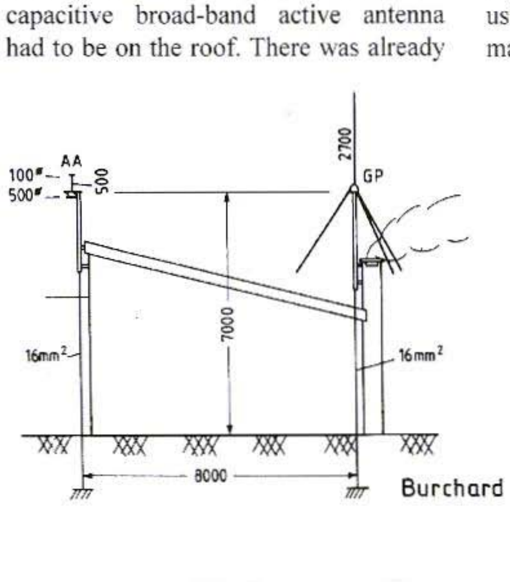

Fig.18: Configuration of Active Antenna AA on the House Roof at the same Height as Ground Plane Antenna GP, which is otherwise used for Short-Wave Reception

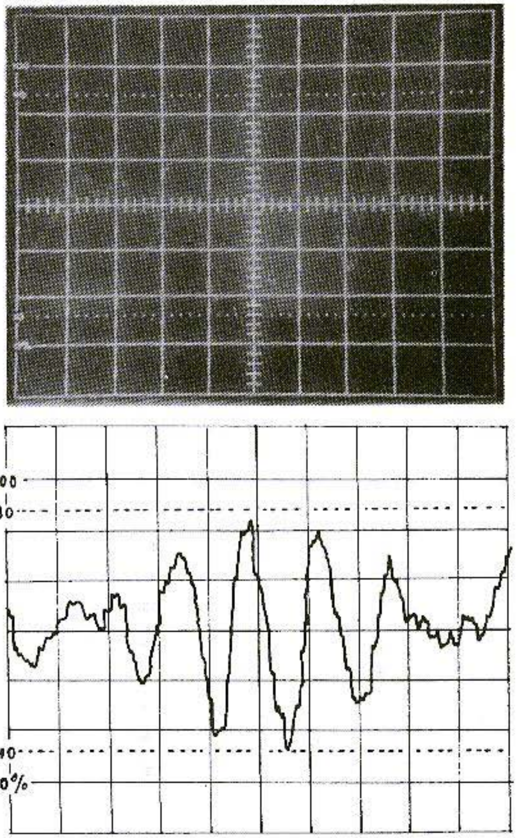

Fig.19:
Reception of two nearby Medium-Wave Transmitters led initially to Saturation. The Image was obtained following Remedial Measures which are described in the text:

left) Original Photo from Oscillograph Screen

below) Hardcopy drawn from Negative

Y: 0.2 V/div; X: 1 μs/div

mitters were causing saturation. This could only be the two 100kW stations in Nairobi, which are 11 and 17km respectively from the reception point and working at 612 and 747 kHz. The total voltage generated by them was much higher than the maximum swing of the active antenna output. It was estimated that they delivered a field strength of approximately 500mV/m.

What I have done now to remedy the situation is to reduce the input resistance of the amplifier. 10kΩ fixed resistance, together with an antenna capacitance of 5pF, gives high-pass behaviour, with a limiting frequency of 3.2 MHz. The interfering medium-wave transmitters are damped by more than 12dB, whilst there is scarcely any impairment in the short-wave range. The oscillogram in Fig.19 shows that this was the right thing to do. The curved trace, now unlimited, looks like a beat effect, because the two transmitters are received at about the same field strength. Short-wave transmitters produce the small ripples on the curve. The reason they are so small, although two 250kW stations are operating 39km away, is because their ground waves suffer considerably more attenuation than those of the medium-wave transmitters.

The quality of the screen photo leaves something to be desired. This is due to the fact that once again I was up against the limits of my capabilities. A writing speed of 20 - 30km/s is the best that can be obtained with the oscilloscope (f = 50 MHz, UB = 10kV), the film used (400ASA), and the maximum focal aperture of the camera (2.8). 50km/s is what was needed here. The hard copy drawn in the dark room, based on the enlarged negative, may be easier to read but does not reproduce all the details faithfully.

Experiments could now be carried out to determine the degree of influence exerted by the top capacity and the ground plate. The result can be seen in Fig.20. A calibration staircase for the rectified voltage in equivalent input power can be seen on the right, to give some idea of the strength of reception. Except for the start and saturation periods, the gradient is 1.8 dB/div. Remember that the dBm reading refers to the power received by the 51Ω resistance in Fig.15. It would be more correct, in physical terms, to have a μV scale or, even better, a μV/m scale. Both can be obtained through simple conversion, but this is not something we are concerned with here.

On the basis of transmissions being received from three transmitters in different frequency bands, at different distances and in different directions, it is unambiguously clear that neither the top capacity nor the ground plate have any measurable influence on the reception voltage. The Voice of Germany transmitter from which transmissions were received in the 19m band is in Sri Lanka, 5700km East of here. Radio Moscow, broadcasting in the 13m band, is 7200km to the North. Finally, the Kenya Broadcasting Corporation's transmitter, from which transmissions were received in the 4m band, is one of those 250kW transmitters already mentioned which are 39km away. This station certainly has the best reception quality, because the ground wave arrives without any selective fading, but it has the greatest fading depth of 45dB. The stress on the AGC is considerable, and the use of logarithmic demodulation in the following receiver, which is here wired up downstream, gives an audible advantage (simply because nothing can be heard of the 45dB signal fluctuation!).

At the time of the day in question, the other two transmitters can be received rather well (The Voice of Germany) and rather badly (Radio Moscow). The fading depth for each of them was only about 30dB.

A few hours later, a comparison was made between the ground plane and the active antenna. The result can be seen in Fig.21. The Voice of Germany is now being received rather more strongly, but inter-modulations can be heard in the field strength troughs. The ground plane certainly supplies 16.5dB volts less on average, so that noise can be heard in the field strength troughs, but no inter-modulation products of any kind can be heard. They may be covered by noise.

The reception of Radio Moscow at this time is poor with both antennae. Frequent disappearance in noise when the ground plane is used can be compared with frequent disappearance in chirping and external modulations with the active

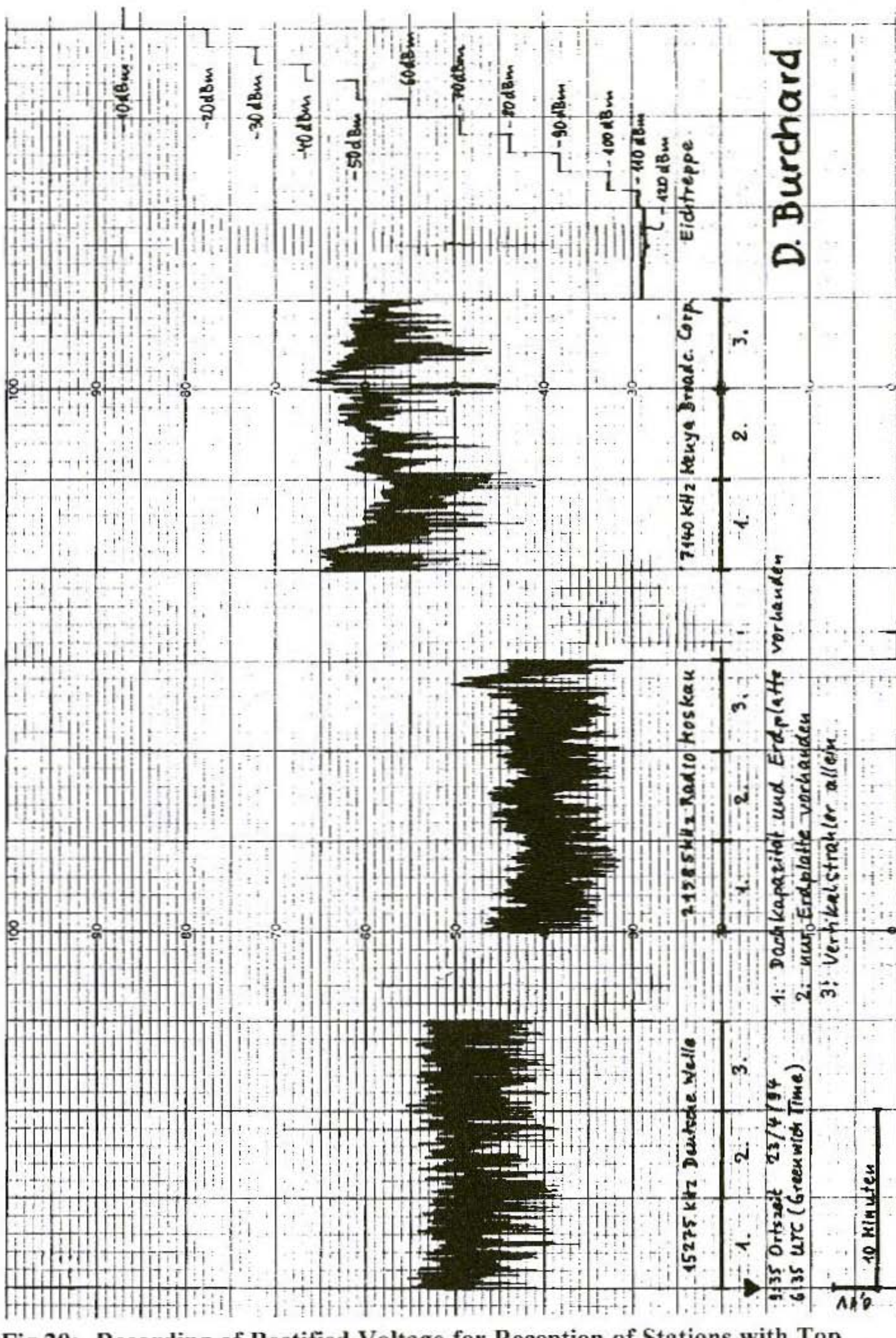

Fig.20: Recording of Rectified Voltage for Reception of Stations with Top Capacity and Ground Plate (1), Ground Plate only (2), Neither (3)

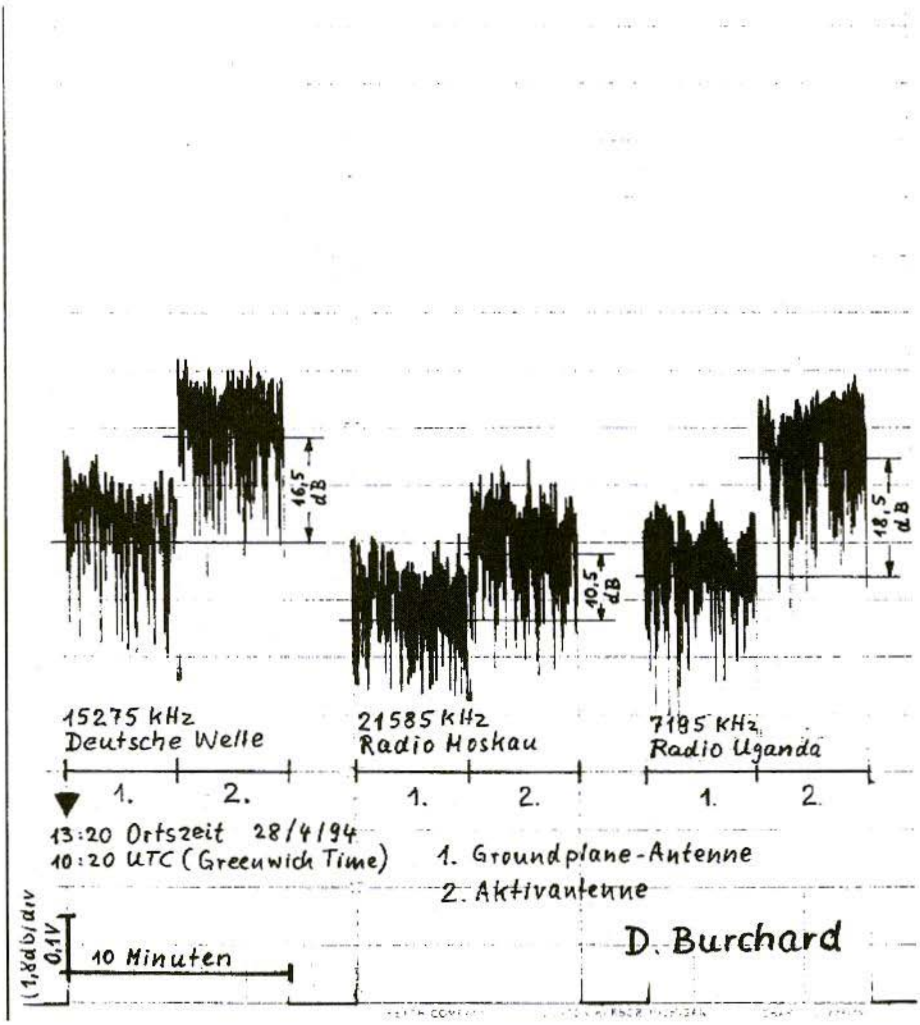

Fig.21: Recording of Rectified Voltage for Reception of Various Transmitters with Ground Plane (1) and Active Antenna (2) using a Configuration as per Fig.18

antenna. The mean level difference is only 10.5dB, and it can be assumed that at the top end of the short-wave range, where the ground plane comes into resonance, the level difference will be rather small.

Since in the meanwhile the Kenya Broadcasting Corporation had switched over to the midday siesta, Radio Uganda (550km West-North-West of here) was now received in the same band. Reception with the active antenna was reasonably good and with the ground plane it was rather poor. The level difference had increased to 18.5dB. In none of the three cases was the gain in reception quality as great as the level difference between the ground plane and the active antenna would lead us to expect. There is little external noise, at this time of day at least. It was thus clear that it is not the internal noise which determines the lowest level of reception, but the dregs from all possible inter-modulations. At night, when the external interference is considerably greater, there are even situations in which the ground plane is superior.

10. SUMMARY

Experience with the medium-wave transmitters shows that the requirement for a compatibility of 1V/m field strength is in no way exaggerated. In Central Europe, it will possibly be necessary to lay down even higher values. But even the 1V/m means that the amplifier output must be capable of delivering up to 10Vpp into 50Ω, which corresponds to 25mW (+24dBm). The current consumption would go up considerably, to an estimated 150mA.

The IM suppression would have to be increased to 120dB. If work is being carried out with a band width smaller than 7 - 10 kHz, then the demands are even greater! The active antenna described here is still 33dB short of 120dB. Naturally, the characteristics of the subsequent receiver would also have to be better, which might scarcely be possible using broad-band concepts. We know from spectrum analysers that there seems to be a sound barrier at "100dB on the screen", even if it is only a matter of cost. So once again we must think about pre-selection, or at least sub-octave band-pass filters. The further forward they are mounted in the signal path, the better they will work. And for this reason a reduced input resistance of the active antenna is better than a really great filter after it.

These problems can be diminished by using a shorter antenna rod. The signal voltage is then reduced and the internal noise is increased, because the Zq.Ir noise increases.

The rod can also be given a capacitive load. This also reduces the signal voltage and the internal noise too, because the Zq decreases, even if not to the same extent as the signal. Capacitive loading is equivalent to the omission of the Ce compensation. We can no longer talk of the "harmful" input capacitance. A design without compensation, such as [5], must not be disadvantageous in operation.

Finally, it appears from the external noise behaviour shown in Fig.5 that for shorter rod antennas are sufficient at low frequencies. Instead of shortening, we can impose an Ohmic load on a sufficiently long rod for the short-wave range (0.5m). If the external noise is greater than 500μV at 20 kHz, but the internal noise is less than 2μV, then a load may be imposed such that the input voltage falls to 1/250. The rod could be given a 6kΩ load, which is very near to the 10kΩ which I used to reduce the voltage of the medium-wave transmitter.

What comes out of this in the end is that the amplifier input need not be capacitance-free or particularly high-Ohmic for the **purposes of reception**. But both conditions must be fulfilled if the aim is to measure field strengths, for which a constant conversion factor is required, irrespective of the frequency. The circuit given in [3] fulfils its purpose, since the input capacitance there is very low and the frequency range of the amplifier is very wide.

The top capacity and the ground plate have no influence on the reception voltage, and only a slight influence on the internal noise, due to the fact that they increase the capacity. It is better to leave them aside completely.

Apart from a small glow lamp with an ignition voltage of 70V, no measures were taken here in the amplifier to drain any over-voltage on the antenna conductor. True, when operations commenced it was not at all clear whether a serviceable active antenna would even be obtained. And even now I am not at all sure that I want to have one. To my knowledge only such antenna of this type are secure against a direct lightning strike that have directly earthed antenna conductors. Such constructions are used in passive antennae. And then, I live in an area which has considerably fewer thunderstorms than my previous home in Germany. I would have to wait a very long time for some lightning, or set up a high-voltage laboratory. There is a lightning research institute on San Salvatore near Lake Lugano in Switzerland. Perhaps a radio ham from Switzerland can get some information from them on how to "harden" amplifiers with a FET input?

Perhaps to end with I should again refer to something which has been known for a very long time, i.e. that antennae with restricted band widths also have their advantages. They keep out signals from outside the band, and thus reduce the possibilities of inter-modulation quite considerably.

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